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PERFORMANCE OF A HIGH-VELOCITY PULSE-JET FILTER, III

by

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16. ABSTRACT The report gives results of a continuing study of the performance of a high-velocity pulse-jet filter. Such filtration has distinct advantages over low-velocity filtration in that the equipment required to clean a gas stream is reduced in size and initial cost as filtration velocity increases. Although high filtration velocity brings on a number of problems, some of them can be dealt with using the information in this report. The study indicates that penetration by particle collection and subsequent seepage (not straight-through penetration) is the primary mechanism by which penetration occurs. A model is presented which encompasses both mechanisms. The model was useful in showing the general trends that should occur with changes in filter operating conditions, but additional information is required to test its ability to predict penetration. Tests were designed to measure the actual fraction of fly ash removed from a polyester felt under typical pulse-jet conditions. Test results showed that failure to remove dust with the cleaning pulse, as well as redisposition, contributed to high pressure drop in pulse-jet filters with nonwoven fabrics.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Felts	Pollution Control	13B	
Filtration	Polyester Fibers	Stationary Sources	07D	
Pulsation	Penetration	Fabric Filters	14B	14G
Jets	Seepage	Pulse-jet Filters	20D	08H
Nonwoven Fabrics	Fly Ash		11E	21B
Mathematical Models	Dust		12A	11G

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ABSTRACT

High velocity pulse-jet filtration has distinct advantages over filtration at low velocities by pulse-jet filtration in that the equipment required to clean a gas stream is reduced in size and first cost as filtration velocity increases. However, high filtration velocity brings a number of problems as well, some of which can be dealt with using the information presented in this report.

Presently, there is no effective way to interpret or predict dust penetration through a pulse-jet cleaned fabric filter. This report presents a model which considers penetration straight through the filter and penetration by particle collection and subsequent seepage. Although numerous studies have been devoted to penetration by the straight through process, a comparison of these data with the results of the present study indicates that seepage and not straight through penetration accounts for virtually all penetrating dust. Although insufficient information is available to use the present model to predict penetration on an absolute basis, the model shows the direction of changes in filter operating conditions with changes in important operating conditions such as filtration velocity and pulse pressure, and suggests areas requiring additional research.

All our results suggest that an understanding of the factors that affect dust retention by the fabric is the key to understanding the performance of pulse-jet cleaned filters. However, mechanisms governing the removal of dust from non-woven fabrics used in pulse-jet filters are still poorly understood. Prior studies have demonstrated that a large amount of dust can remain on a fabric immediately after cleaning due to: 1) failure of the cleaning pulse to remove dust from the fabric; 2) redeposition of dislodged dust back onto the fabric; 3) a combination of the two mechanisms. Tests described here were designed to measure the fraction of fly ash removed from a polyester felt and discharged to the dust hopper under typical filter cleaning conditions. The fraction of dust removed from the fabric during these tests ranged from 2% to 35%. The fraction removed under cleaning conditions thought to be "typical" was about 12%. Such poor cleaning efficiencies indicate that redeposition is not the only cause of high pressure drop in pulse-jet filters and point to the need for improving the efficiency of cleaning methods used to remove dust from non-woven fabrics.

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SECTION 1

INTRODUCTION

This report is the third in a series dealing with performance of pulse-jet cleaned fabric filters. Although each report can be read and understood independently, they are all aimed at the same goal - a better understanding of the factors controlling pulse-jet filter performance and maximum understanding may be gained by reading all of the reports in this series.

Although pulse-jet cleaned filters comprise a substantial portion of the fabric filter market in the United States, the factors that affect filter efficiency and pressure drop are not yet well understood. It is likely that additional improvement in filter performance can be achieved when a better understanding of the factors that affect performance can be applied to filter design and operation.

This report describes studies of pulse-jet cleaned fabric filters operated at filtration velocities ranging from conventional to high. It consists of two parts: first, a model for dust penetration through pulse-jet cleaned filters and the second, an investigation of the forces necessary to remove deposited dust from the surface of a fabric.

SECTION 2

CONCLUSIONS

Dust can pass straight through a pulse-jet cleaned fabric filter and can also pass through by collection and subsequent seepage. In Section Four is a model that describes penetration by each of these processes. The model reflects empirical data that show that most dust loss from operating filters takes place by seepage alone. Although insufficient information is presently available to use the model for penetration predictions on an absolute basis, the results may be used to indicate the penetration trends that will occur with changes in such operating variables as filtration velocity, cleaning pulse pressure, and fabric type. These results indicate that research should emphasize seepage of collected particles through the filter rather than the process of particle collection itself.

Although pulse-jet cleaning has advantages over other fabric filter cleaning systems, an inability to discharge a large fraction of the deposited dust to the dust hopper can have a seriously adverse effect on system pressure drop. Bench-scale tests indicate that pulse-jet cleaning may become very inefficient for removing deposited fly ash from the surface of polyester felt. Experiments performed over a wide range of fabric cleaning conditions measured dust removal efficiencies from 2 to 36%. Tests under conditions thought to be typical of a full-scale system resulted in a dust removal efficiency of about 12%.

The fraction of dust removed from a felt fabric during cleaning was found to be closely correlated with the kinetic energy imparted to the dust deposit. If cleaning energy could be transferred to the dust deposit more efficiently, either by improving the pulse-jet or by applying different cleaning methods, non-woven fabric filters could be operated at higher filtration velocities or at lower pressure drops.

SECTION 3

RECOMMENDATIONS

The present work suggests that most dust penetration through pulse-jet filters is by seepage; comparatively little dust penetrates straight through the fabric without stopping. Therefore, theoretical models used to predict or interpret penetration data for pulse-jet filters must consider penetration by seepage. The size of particles penetrating a filter by seepage may be much different from the sizes that result from straight through penetration. Regrettably, few data are available as yet to describe these relationships. Penetration through a pulse-jet filter can be decreased by: (1) reducing filtration velocity, (2) reducing the amount of the dust left on the surface of the bags after the cleaning pulse, and (3) extending the time interval between cleaning pulses. Normally, these objectives cannot be pursued independently, and actions taken to reach one may adversely affect the others. For example, extending the interval between cleaning pulses may increase the amount of dust on the bags, all else remaining equal. However, advances in baghouse or fabric technology may permit progress in these areas.

The key to improving baghouse performance is a better understanding of all the factors affecting fabric cleaning because pulse-jet cleaning as presently practiced is not efficient. More effective means for removing the surface dust deposited on fabrics need to be developed and new fabrics need to be developed that can be cleaned more effectively.

Pulse-jet cleaning effectiveness is determined not only by the fabric cleaning efficiency but also by the amount of dust redeposition. Little is known about redeposition, but it is probably affected by such system parameters as filtration velocity and baghouse geometry. The relative importance of fabric cleaning efficiency and dust redeposition in causing high pressure drop should be studied.

SECTION 4

THEORY FOR PENETRATION IN A PULSE-JET CLEANED FABRIC FILTER

INTRODUCTION

In spite of many attempts to model penetration through fabric filters(2-5), there is presently no satisfactory way to predict dust penetration through a pulse-jet cleaned fabric filter. This is not because of insufficient interest in the problem. Pulse-jet filters have captured a substantial portion of the fabric filter market(1), and the efficiency with which they operate is of strong interest to regulatory officials, to industrial users who must meet emission regulations, and to equipment manufacturers who supply these filters with a performance guarantee.

Performance characteristics which must be considered when modeling penetration include: (1) particle collection by clean fibers in a new fabric, (2) particle collection by the dust deposit accumulated on and in these fabrics, and (3) retention of this dust so it does not seep through the fabric during the rather violent cleaning cycle.

Penetration Straight Through a Clean Fabric

Particle collection by isolated, clean cylinders or fibers has been well studied, and adaptation of single fiber collection models into models for particle penetration through an array of clean fibers are well known(6). Fraser and Foley(4) have made use of this work to describe penetration through a clean woven fabric and Hampl and Rimberg(2) have adapted clean fiber bed theory to a study of particle penetration through clean felt of the kind used in pulse-jet cleaned filters. The latter found that penetration of 0.35 to 1.1 μm particles through clean, new industrial felts ranged from 20 to 70% at typical pulse-jet filtration velocities, penetrations that are much higher than the 1% or less generally found for intermittently cleaned industrial filters using fabrics well conditioned with dust(7-9). Although agreement is excellent between penetration theory and data for clean, new felt fabrics(2), the performance of new felt in the laboratory is clearly different from that of a well conditioned felt when used in an industrial pulse-jet filter.

Penetration Straight Through a Dust Deposit

The accumulation of dust in and on a fabric can affect dust collection in several ways. At low dust accumulation, before a continuous dust deposit forms on the fabric surface, dust particles collect on previously collected particles adhering to the fibers, as well as on the fibers themselves. Because of the greater collection efficiency of the deposited dust particles for collecting additional particles, the apparent efficiency of individual fibers increases as dust collects upon them so that fabrics conditioned with dust have lower penetration than bed(6) or fabric(3,4) composed of new, clean fibers. Fraser and Foley (4) modeled the effect of dust accumulating on woven fabrics by assuming the effect equivalent to a reduction of fiber diameter.

At high dust holdings, when the dust deposit is continuous and uniform on the fabric surface, the deposit acts as a filter cake and efficiency improves further. Cooper and Hampl(3) studied dust penetration straight through a well-developed dust deposit using an entirely theoretical model under the assumptions that impaction, interception (sieving), and diffusion are the important particle collection mechanisms. They determined that essentially no particles larger than 1 μm or so should pass through the dust deposit unless pinholes are present in it. Although models for penetration straight through a dust deposit are not as well developed as those for penetration straight through a clean fiber bed or a clean fabric, theory suggests that a continuous, unflawed deposit should collect virtually all particles from the aerosol passing through it. Theory predicts that penetration straight through a deposit should decrease with increasing particle diameter and increasing filtration velocity(3) for particle diameters larger than a few tenths micrometer.

Although penetration data must be carefully examined with reference to the conditions under which the tests were made, tests on new, clean felts by Hampl and Rimberg(2) show the decrease in penetration with increasing particle diameter and filtration velocity predicted by straight-through theory and bench-scale experiments by Afify and Mohamed(10) and by Hall(11) show that penetration through an uncleaned felt becomes very low when a substantial dust deposit builds up on it. These conclusions generally confirm the Fraser-Foley(4) and Cooper-Hampl(3) theories that virtually no dust penetrates an established dust deposit. However, experiments on uncleaned fabrics are not relevant to the effects of seepage caused by filter cleaning.

Penetration by Seepage

Seepage penetration is defined as a process whereby collected particles later pass through the filter, i.e., seepage is a failure to retain collected dust rather than a failure of

collection. In pulse-jet cleaned filters, most seepage is thought to occur when the conditioned fabric strikes its supporting cage at the end of a cleaning pulse(12). Rapid deceleration of the residual dust deposit causes some particles or agglomerates to separate from the support (fabric fibers or other dust particles). As normal filtration flow resumes, some of these particles or agglomerates are swept through the fabric and into the cleaned gas stream.

Seepage penetration is likely to increase whenever the separation force between the collected dust and its substrate increases. For example, large particles or agglomerates with considerable inertia are likely to break loose more easily than small particles when the fabric strikes its supporting cage smartly at the end of a cleaning pulse. It is reasoned that high filtration velocity, which drives the fabric back onto its cage at a faster rate causes it to hit with greater impact, and thereby aggravates seepage. In contrast, straight-through penetration theory predicts penetration should decrease with increasing particle size and with increasing filtration velocity(2-4) for particles larger than a few tenths micrometer in size. This is opposite to the trends expected from seepage.

PENETRATION MODEL

A reasonable model to describe dust penetration through a pulse-jet-cleaned filter should consider both straight-through penetration and seepage penetration. The rate at which dust passes through the filter can be expressed in terms of outlet mass flux, the mass of dust that penetrates per unit fabric area per unit time:

$$N = N_{st} + N_{se} \qquad (4\text{-}1)$$

in which N represents the total outlet mass flux, N_{st} is the outlet flux due to straight-through penetration, and N_{se} is the flux due to seepage.

The total straight-through flux, for particles of all sizes, will depend on penetration for particles of each size in the inlet aerosol:

$$N_{st} = v\, c_i \int_0^1 P_{st}\, dG \qquad (4\text{-}2)$$

in which v is superficial filtration velocity, c_i is the overall mass concentration for particles approaching the filter, P_{st} is the fraction of particles of a particular size that pass straight through the filter, and dG is the mass fraction of all incoming particles which are of that size.

If the relationship between particle diameter and straight-through flux is needed, then relationships among particle diameter, straight-through penetration, and inlet dust size distribution must be known. However, if an overall value for straight-through flux is sufficient, the overall mass fraction of the inlet dust that passes straight through the filter, P_{st}, can be used in place of the integral in Equation (4-2).

As discussed above, dust that seeps through a pulse-jet-cleaned fabric may be comprised essentially of dust driven through the fabric when the fabric strikes its supporting cage as a cleaning pulse ends and filtration resumes. Deceleration of the dust held by the fabric as it strikes the cage may cause a separation force sufficient to free some dust which normal filtration air can then sweep through into the cleaned gas stream. If so, then seepage flux will be:

$$N_{se} = \frac{w}{t} \int_0^1 \varepsilon \, dH \qquad (4\text{-}3)$$

in which w is the mass areal density of the total dust deposit on the fabric as it strikes its cage, t is the time interval between cleaning pulses, ε is the fraction of particles or agglomerates of a particular size in the dust deposit that are separated from the dust deposit as the fabric strikes the cage, and dH is the mass fraction of all particles or agglomerates in the dust deposit that are of that particular size.

If the relationship between particle diameter and outlet flux is required, the relationships among ε, dH, and particle or agglomerate size must be known. If an overall mass outlet flux is sufficient, an overall mass-weighted average for ε can be used, $\bar{\varepsilon}$, in place of the integral in Equation (4-3). Insufficient data are presently available to allow evaluation of the integral in Equation (4-3) and in the following discussion $\bar{\varepsilon}$ will be used.

The overall mass fraction of dust separated from a conditioned fabric, $\bar{\varepsilon}$, can be related(14) to the applied area-specific force causing the separation, F_s/A. The exact relationship between fraction of dust separated and separation force applied is not known, and is presently under investigation at this laboratory; for example, see section 5 of this report. Pending the outcome of this work it will be assumed that these variables are proportional:

$$\bar{\varepsilon} = \frac{k^* F_s}{A} \qquad (4\text{-}4)$$

Impulse-momentum considerations say that the area-specific separation force applied, F_s/A, times the time over which this force acts, t^*, will equal the momentum of the area-specific dust deposit as it begins deceleration upon striking the cage:

$$\frac{F_s t^*}{A} = w v \qquad (4\text{-}5)$$

Substitution of Equations (4-4) and (4-5) into Equation (4-3) yields:

$$N_{se} = \frac{k^* w^2 v}{t^* t} = \frac{k w^2 v}{t} \qquad (4\text{-}6)$$

in which the unknown proportionality constant, k^*, and the time necessary to stop the fabric as it strikes its cage, t^*, are combined in a new constant, k, which should depend on the dust separation and retention characteristics of the fabric and fabric elasticity.

Equations (4-2) and (4-6) can be substituted into Equation (4-1) to give an expression for overall outlet flux through the pulse-jet cleaned filter:

$$N = c_i v \overline{P_{st}} + k \frac{w^2 v}{t}. \qquad (4\text{-}7)$$

EXPECTED TRENDS IN OUTLET FLUX

Equation (4-7) predicts the effects of changes in filter operation on overall outlet flux, N. First, consider the case in which straight-through penetration is much more important than seepage; that is, the first term on the right side of Equation (4-7) is considerably larger than the second:

$$N \doteq c_i v \overline{P_{st}} \qquad (4\text{-}8)$$

In this instance, Equation (4-8) shows that decreases in inlet dust concentration, c_i, should cause a decrease in outlet flux. However, Dennis(9) has determined from field and laboratory studies(7,15) that the mass emission rate or flux from a fabric filter is essentially constant despite changes in inlet concentration.

Straight-through theory predicts that factors which decrease overall penetration, $\overline{P_{st}}$, such as increasing diameter for particles larger than a few tenths micrometer, or increasing dust deposit areal density should also decrease outlet flux. However, Leith and First(8) determined that large particles pene-

trate a pulse-jet filter as readily as small particles, at variance with this prediction. Data(16,17) discussed later in this section of the report indicate that more dust penetrates if the dust deposit areal density increases, also at variance with this prediction.

The effect of increased filtration velocity on straight-through outlet flux is unclear. Equation (4-8) suggests that outlet flux should increase with velocity, v, if all else remains constant; however, increased velocity should also decrease penetration, $\overline{P}_{st}$, for particles collected by impaction so that the net effect of velocity changes on outlet flux is uncertain. In summary, straight-through penetration theory predicts trends generally at variance with those determined experimentally for changes in pulse-jet filter operating conditions such as inlet dust concentration, particle diameter, and areal density of the dust deposit.

Next, consider the case in which seepage is much more important than straight-through penetration, that is, the second term on the right side of Equation (4-7) is considerably larger than the first:

$$N \doteq k \frac{w^2 v}{t} \qquad (4\text{-}9)$$

Equation (4-9) predicts that outlet flux should decrease with decreases in the areal density of the dust deposit, w, in marked contrast to straight-through theory, but in agreement with experimental data reported by Ellenbecker(16) and by Leith et al.(17). Equation (4-9) also indicates that decreases in filtration velocity should decrease outlet mass flux, in agreement with several experimental studies(8,18-20) using pilot scale and full scale pulse-jet filters. Dennis(9), Hall(11), and Löffler(13) have shown that outlet dust concentration from a pulse-jet cleaned filter increases substantially but momentarily, immediately after cleaning. Modifications to the cleaning pulse which ease the cleaned bag back to its supporting cage gently so that it hits with less impact have been shown to decrease penetration compared to that found with normal pulse-jet cleaning.(21). These results are expected if seepage associated with pulse-jet cleaning causes penetration.

Leith and First(10) measured the relative amounts of straight-through flux and seepage flux for fly ash penetrating a pulse-jet filter using untreated but conditioned polyester bags at superficial filtration velocities from 50 to 150 m/s. Outlet flux was very low for the straight-through mechanism under all conditions, but the seepage mechanism increased with increasing filtration velocity. In general, the conclusion was reached that seepage accounted for essentially all the dust that passed

through the pulse-jet filter and was particularly important at high filtration velocities.

Although Equation (4-9) is presently inadequate to describe the dependence of outlet flux on particle diameter, this relationship can be incorporated into the equation when information adequate to allow integration of Equation (4-9) becomes available. It should be clear that penetration by particle size will be greatly influenced by filtration velocity, dust loading, pulse pressure, etc. In summary, penetration trends predicted by seepage theory seem generally to agree with trends observed in experiments conducted over a range of pulse-jet filter operating conditions. These trends require precise quantification to make possible a fully comprehensive mathematical model of a pulse-jet cleaned filter. These tests are presently under way at this laboratory.

COMPARISON OF MODEL WITH DATA

If seepage alone accounts for nearly all the dust penetration from a pulse-jet cleaned fabric filter, Equation (4-9) predicts that a log-log plot of outlet dust flux versus the group w^2v/t should yield a straight line with a slope of unity and an intercept at log(k). Data(16,17) adequate to check this prediction are summarized in Tables (4-1) and (4-2). Bags made from untreated polyester felt and Gore-tex felt were tested in a three-bag pulse-jet filter at superficial filtration velocities from 50 to 150 mm/s. Outlet dust concentrations were measured, and total outlet flux calculated. The areal density of the dust on the bags was measured by weighing the bags and subtracting the weight of the clean new fabric. The interval between cleaning pulses was 60 s per bag in each test.

Figure (4-1) is a log-log plot of outlet dust flux, N, against w^2v/t. The data for both bag types scatter about lines with a unit slope as Equation (4-9) indicates will occur when outlet flux caused by straight-through penetration is negligible and seepage is caused by deceleration of the bag as it hits the supporting cage. A least squares fit for Equation (4-9) to the data shown in Figure (4-1) gives values of $k = 0.0077$ m·s/kg for untreated polyester fabric with coefficient of determination, $r^2 = 0.92$, and $k = 0.034$ m·s/kg for the Gore-tex fabric with $r^2 = 0.96$. The higher value for constant k found for Gore-tex fabric should not necessarily be interpreted to mean that penetration in an operating filter will be higher using Gore-tex fabric, as this fabric retains less dust. Although Equation (4-9) shows that outlet flux increases with increasing k, it decreases with the square of areal dust density, w. Inter-fabric comparisons require knowledge of both factors.

Figure (4-2) is a plot of outlet flux determined by Equation

TABLE 4-1. PENETRATION DATA: PULSE-JET CLEANED FILTERS(16,17)

Fabric	N, $kg/m^2 \cdot s$	v, m/s	w, kg/m^2	t, s	w^2v/t, $kg^2/m^3 \cdot s^2$
Gore-tex	3.47×10^{-7}	0.05	0.108	60	9.63×10^{-6}
"	6.30×10^{-7}	0.05	0.149	60	1.84×10^{-5}
"	6.90×10^{-7}	0.05	0.157	60	2.05×10^{-5}
"	3.38×10^{-7}	0.05	0.119	60	1.18×10^{-5}
"	2.58×10^{-6}	0.10	0.222	60	8.21×10^{-5}
"	3.73×10^{-6}	0.10	0.215	60	7.71×10^{-5}
"	1.31×10^{-6}	0.10	0.142	60	3.35×10^{-5}
"	1.55×10^{-6}	0.10	0.195	60	6.31×10^{-5}
Polyester	7.76×10^{-7}	0.05	0.384	60	1.23×10^{-4}
"	9.77×10^{-7}	0.05	0.420	60	1.47×10^{-4}
"	8.64×10^{-7}	0.05	0.349	60	1.01×10^{-4}
"	1.11×10^{-6}	0.075	0.423	60	2.23×10^{-4}
"	1.35×10^{-6}	0.075	0.546	60	3.72×10^{-4}
"	1.13×10^{-6}	0.075	0.348	60	1.51×10^{-4}
"	1.62×10^{-6}	0.10	0.402	60	2.69×10^{-4}
"	3.42×10^{-6}	0.10	0.501	60	4.19×10^{-4}
"	1.83×10^{-6}	0.10	0.372	60	2.30×10^{-4}
"	2.81×10^{-6}	0.125	0.338	60	2.37×10^{-4}
"	2.44×10^{-6}	0.125	0.331	60	2.28×10^{-4}
"	2.74×10^{-6}	0.125	0.441	60	4.04×10^{-4}
"	1.55×10^{-5}	0.15	0.658	60	1.08×10^{-3}
"	1.37×10^{-5}	0.15	0.700	60	1.23×10^{-3}

TABLE 4-2. OPERATING CONDITIONS: PULSE-JET-CLEANED FILTERS(16,17)

Pulses	
Frequency	once each 60 seconds to each bag
Pressure	690 kPa
Dust	
Type	fly ash precipitated from coal-fired utility boiler
Count median diameter	0.30 μm
Geometric standard deviation	2.7
Feed rate per unit bag area	$3.1 \times 10^{-3} kg/m^2 \cdot s$
Bags	
Number	3
Size	114 mm diameter and 2.44 m long
Construction	Polyester: no surface treatment Gore-tex: ptfé laminate over polyester felt
Weight	Polyester: 0.54 kg/m^2 Gore-tex: 0.46 kg/m^2
Permeability	Polyester: 29 cfm/ft^2 at ½ inch of water Gore-tex: 13 cfm/ft^3 at ½ inch of water

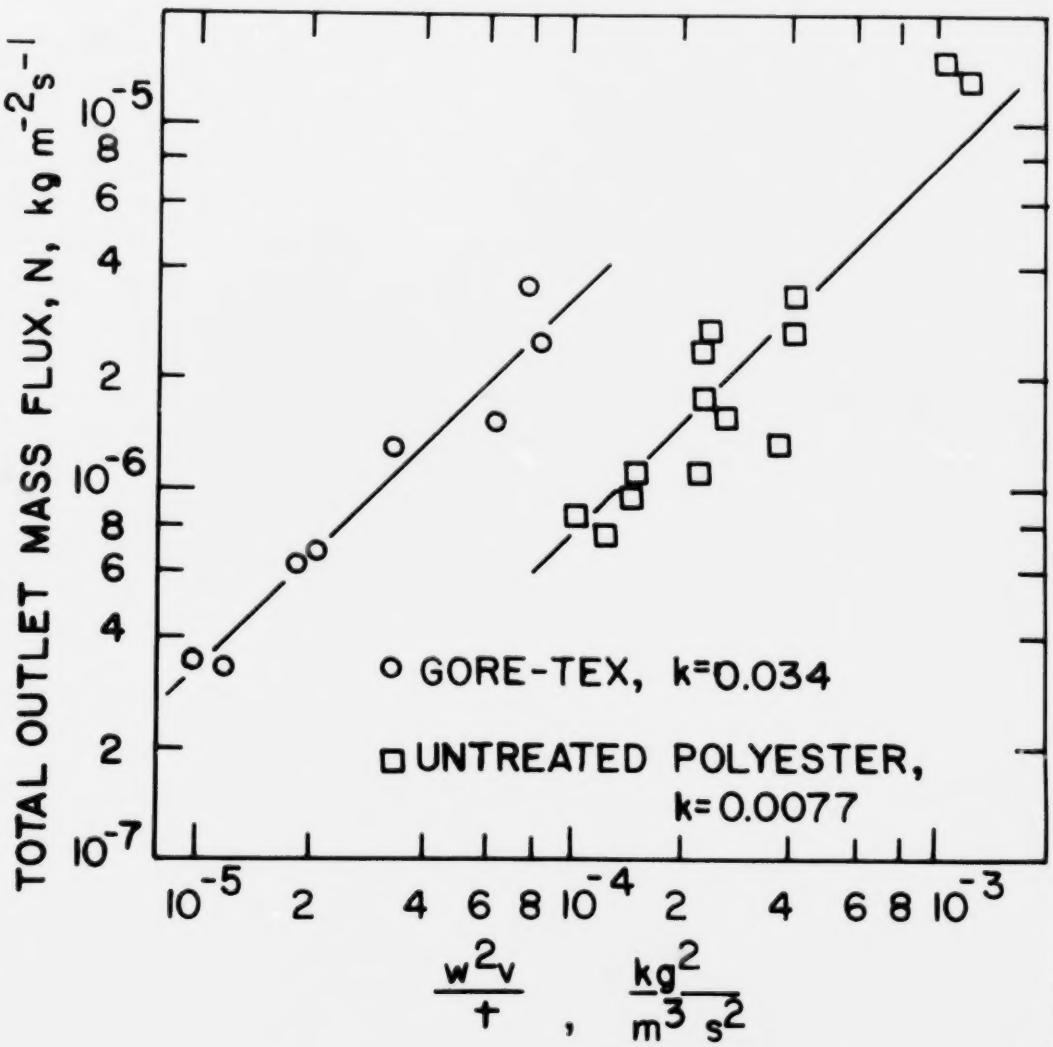

Figure 4-1. Total outlet mass flux, N, versus w^2v/t, for bags made from Gore-tex and untreated polyester felt.

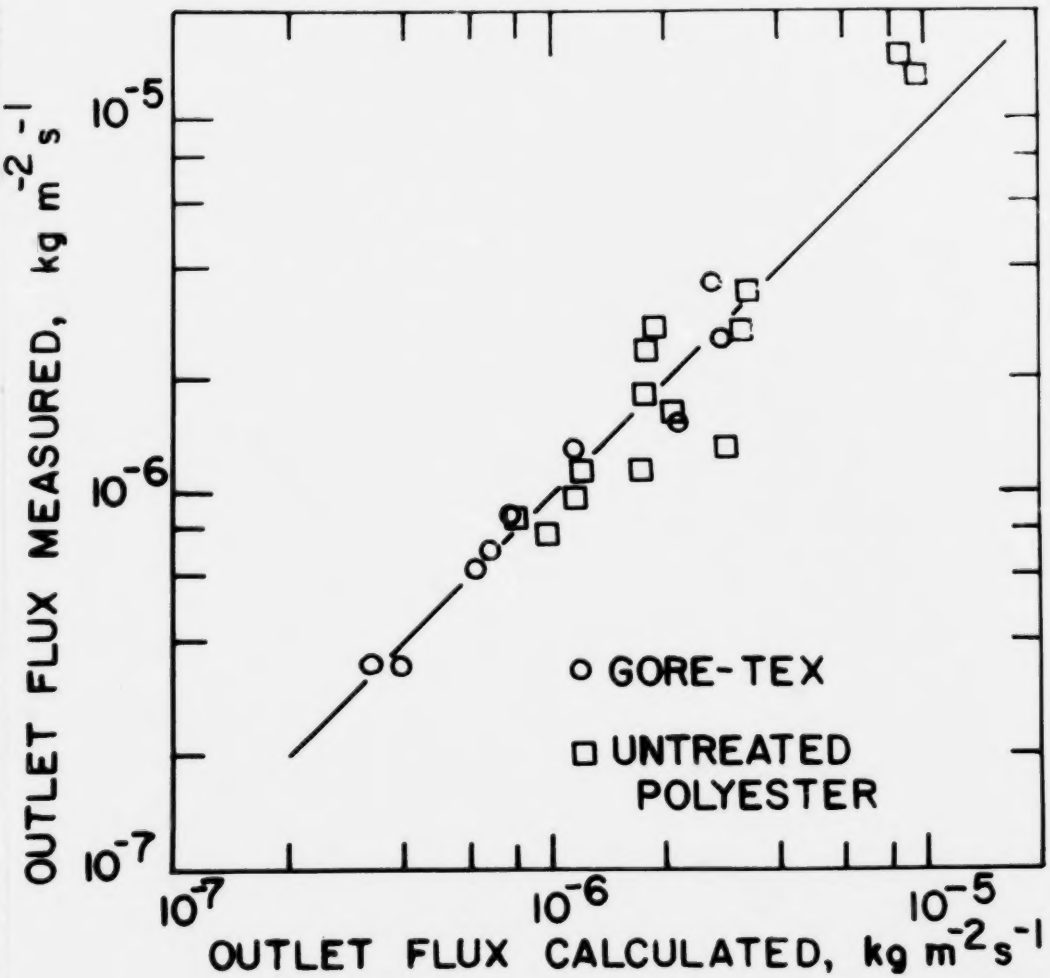

Figure 4-2. Total outlet mass flux measured versus total outlet mass flux predicted using Equation 9 with k = 0.034 m·s/kg and k = 0.0077 □·s/kg for Gore-tex and untreated polyester bags, respectively.

(4-9) using these k values against experimental measurements of outlet flux. It shows that, in general, Equation (4-9) predicts filter outlet flux reasonably well over a relatively broad range of filtration velocities and dust areal densities, and for fabrics of two kinds.

DISCUSSION

To predict outlet mass flux using Equation (4-9), values are needed for filtration velocity, v, time between cleaning pulses, t, constant, k, and areal density of the dust deposit, w. Although velocity and time between cleaning pulses are ordinarily known, the other two parameters might not be known. At present the only way to determine constant k is to evaluate data as done in Figure (4-1). Our data to the present indicate that constant k depends on fabric type, although it is likely to depend as well on the characteristics of the dust collected, pulse pressure, filtration velocity, and other parameters.

The areal density of the dust deposit on the fabric is also likely to be unknown. The magnitude and distribution of the dust deposit on an operating nonwoven bag can be measured with difficulty(22). A procedure for calculating the areal density of the dust deposit on a pulse-jet cleaned filter has recently been developed as part of a theoretical model for pressure drop(14). This procedure, however, requires other information concerning the resistance of the fabric and the specific resistance of the dust deposit which may not be available. Regrettably, it is not presently possible to use Equation (4-9) to predict quantitatively the outlet flux from a pulse-jet-cleaned fabric filter; further work is necessary.

However, the model is useful to predict the direction of outlet flux to changes in pulse-jet filter operating variables. Equation (4-9) shows that outlet flux increases with increasing filtration velocity. Increased pulse pressure should decrease the areal dust density, w; if so, outlet flux should also decrease although sufficient dust must remain on the filter to assure good collection of incoming dust. Equation (4-9) suggests that increasing t, the time between pulses to each bag, should decrease emissions, but this might also increase the areal density, w, of the dust deposit on the bag. An increase in areal density should increase emissions so that the net effect of pulse interval on outlet flux is unclear. Changes to the size distribution of the dust, to the relative humidity or temperature of the gas stream, or to the electrostatic properties of the dust or fabric may all affect constant k; the relationships between these variables and this constant are presently unknown.

SUMMARY

Dust can pass straight through a pulse-jet-cleaned fabric filter, and can also pass through by seepage. A model is presented which describes penetration by each of these processes. Comparison of the model with data shows that outlet mass flux from operating filters can be accounted for by seepage alone. Although insufficient information is presently available to use the model for penetration prediction on an absolute scale these conclusions suggest that additional research on developing a penetration model should emphasize seepage of collected particles through the filter rather than the process of particle collection itself. Furthermore, these results suggest the trends in outlet flux that should occur with changes in operating variables such as filtration velocity, pulse pressure, and fabric type.

The utility of the present model lies in its ability to interpret penetration characteristics of pulse-jet-cleaned filters that previously could not be explained effectively. The agreement found between data and model predictions for outlet flux over a range of filtration velocities, areal dust densities, and for two different fabrics lends strong support to the validity of the assumptions used in the model's derivation. These results strongly suggest that penetration models which do not consider seepage as an important penetration mechanism are seriously flawed. Furthermore, these results indicate that penetration models intended to describe the fractional efficiency characteristics of a pulse-jet-cleaned filter must consider the agglomeration characteristics and particle size-dependent release characteristics of the fabric and dust deposit, rather than relationships between particle size and straight-through penetration alone. These results suggest which future research is likely to be productive, and which is not.

NOMENCLATURE

c_i	dust inlet concentration, kg/m^3
dG	mass fraction of particles of a particular size in the inlet dust, dimensionless
dH	mass fraction of particles or agglomerates of a particular size in the dust deposit, dimensionless
F_s/A	area-specific force acting to separate the dust deposit from its substrate, N/m^2
k	constant, see Equation 6, $m \cdot s/kg$
k^*	constant, see Equation 4, m^2/N
N	total outlet mass flux, $kg/m^2 \cdot s$
N_{st}	outlet mass flux due to straight-through penetration, $kg/m^2 \cdot s$
N_{se}	outlet mass flux due to seepage penetration, $kg/m^2 \cdot s$
P_{st}	fraction of particles of a particular size that pass straight through the filter, dimensionless

$\overline{P_{st}}$ mass fraction of the inlet dust that passes straight through the filter, dimensionless

t time between cleaning pulses, s

t* time during which dust deposit decelerates, s

v superficial filtration velocity, m/s

w areal density of dust deposit on and in fabric, kg/m^2

ε fraction of particles or agglomerates of a particular size in the dust deposit that are separated from the dust deposit, dimensionless

$\bar{\varepsilon}$ mass fraction of the dust deposit that is separated from the dust deposit, dimensionless

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SECTION 5

DUST REMOVAL FROM NON-WOVEN FABRICS

INTRODUCTION

The pulsed jets of compressed air commonly used to clean non-woven fabrics in fabric filters are inefficient at removing the deposited dust(1,2). Measurements on a pilot-scale pulse-jet fabric filter using fly ash test dust indicate that less than 1% of the dust on a bag is typically removed to the hopper by a cleaning pulse(1,3).

Improving the effectiveness of pulse-jet cleaning offers the potential for dramatically improving pulse-jet filter performance. Both pressure drop and, to a lesser extent, collection efficiency are adversely affected by the failure to clean the fabric efficiently. The basic processes controlling the removal of dust from from non-woven fabrics must be understood if improvements in cleaning efficiency are to be identified. This section of the report describes the results of an experimental program designed to investigate the factors affecting dust removal from non-woven fabrics.

DUST RETENTION

The phenomena by which dust is inefficiently cleaned from a fabric and thus remains present after a cleaning pulse will be referred to as dust retention. The fraction of dust remaining on a bag after cleaning is defined to be the dust retention coefficient, λ:

$$\lambda = \frac{m_a}{m_b} \qquad (5\text{-}1)$$

where m_a is the mass of dust remaining on the bag immediately after a cleaning pulse and m_b is the mass of dust on the bag immediately before a cleaning pulse. The dust retention coefficient can also be stated in terms of the amount of dust which is removed by a cleaning pulse and falls to the hopper, m_h:

$$\lambda = 1 - \frac{m_h}{m_b} \qquad (5\text{-}2)$$

The efficiency of a cleaning pulse is equal to the fraction of dust which falls to the hopper, ε, defined by:

$$\varepsilon = 1 - \lambda = \frac{m_h}{m_b} \tag{5-3}$$

Previous theoretical work(4) has shown that the dust retention coefficient, λ, strongly affects the amount of dust present on the bag at equilibrium just before a cleaning pulse:

$$m_b = \frac{m_o}{1 - \lambda} \tag{5-4}$$

where m_o is the mass of dust deposited on a bag between cleaning pulses. The dust deposit is evenly distributed over the surface of each bag(1), and so can be reasonably described in terms of areal density:

$$w = \frac{w_o}{1 - \lambda} \tag{5-5}$$

where w and w_o are equal to m_b and m_o divided by the bag surface area, A, respectively.

Pressure drop across a dust-conditioned bag is given by:

$$\Delta p = \Delta p_f + \Delta p_d = K_1 v + K_2 v w \tag{5-6}$$

where Δp_f and Δp_d are the pressure drops across the fabric and dust, respectively, K_1 is the conditioned fabric resistance, K_2 is the dust deposit specific resistance, and v is the filtration velocity. Substituting Equation (5-5) into Equation (5-6),

$$\Delta p = K_1 v + \frac{K_2 v w_o}{1 - \lambda} \tag{5-7}$$

The increase in w caused by values of λ approaching unity causes equilibrium pressure drop to increase.

When cleaning is complete, dust retention coefficient, λ, approaches zero and w equals the incremental dust deposit added during cleaning, w_o. In this case the equilibrium pressure drop immediately before cleaning is:

$$\Delta p = K_1 v + \frac{K_2 v w_o}{1 - 0}$$

or:

$$\Delta p = K_1 v + K_2 v w_o \tag{5-8}$$

If K_2 remains constant, the extent that pressure drop exceeds the value predicted by Equation (5-8) is a measure of the dust retention present in the system. Data indicate that equilibrium pressure drops usually exceed by far the value predicted by Equation (5-7). For example, Dennis and Wilder (2) performed experiments using fly ash collected on Dacron felt in a series of single bag pilot-scale experiments. When filtering at 43 mm/s they measured residual pressure drops immediately after cleaning, ranging from 600-1600 Pa corresponding to residual dust deposits of 300-650 g/m^2. The pressure drop across their clean fabric at this velocity was only 30 Pa; the rest of the pressure drop represents a "penalty" due to the failure to clean the fabric more effectively.

Experimental work at the Harvard Air Cleaning Laboratory has demonstrated even greater dust retention at higher filtration velocities(1,3). In experiments on a three-bag fabric filter using polyester needled felt collecting fly ash, residual dust deposits approaching 1 kg/m^2 have been measured when the incremental dust deposit was only 3 g/m^2. The filtration velocity in this case was 150 mm/s; the equilibrium pressure drop was 10 kPa, almost 100 times greater than the pressure drop across the clean fabric and incremental dust deposit at this velocity.

Factors Affecting Dust Retention

Removal of dust from a non-woven fabric takes place in two stages. First, the cleaning pulse separates some fraction of the dust from the fabric. Second, the separated dust falls toward the hopper. Some fraction of the removed dust actually reaches the hopper, but some redeposits on the cleaned bag or adjacent bags. The fraction of dust reaching the hopper, ε, is thus the product of two separate processes:

$$\varepsilon = \alpha\beta \qquad (5\text{-}9)$$

where α = fraction of dust removed from the fabric by a cleaning pulse
β = fraction of removed dust which falls to the hopper.

As discussed above, the fraction of dust reaching the hopper in actual practice is very low; this can be caused by a failure to remove dust from the fabric, the redeposition of the removed dust, or a combination of both factors. Some investigators(5) have assumed that redeposition predominates, i.e., the cleaning pulse removes most of the dust deposit, so that dust retention is caused primarily by redeposition. No experimental evidence has yet been presented, however, to confirm or deny this assumption.

It is important to determine the relative importance of inefficient dust removal and redeposition to inefficient clean-

ing, as system modifications to improve performance (i.e., reduce dust retention) could differ greatly depending on which factor is more important. System modifications which would eliminate redeposition altogether, such as compartmentalization and air flow shut-down, might have no effect on improving dust removal from the fabric.

Dust Removal Mechanisms

Factors affecting the removal of dust from a non-woven fabric by a compressed air pulse are discussed elsewhere(6). The air pulse causes static pressure to increase inside the bag; the difference between this static pressure and the operating pressure drop across the bag during cleaning causes a force which accelerates the fabric and dust outward. The fabric is not stretched tightly around the cage, and so can accelerate radially outward to reach a maximum velocity during cleaning, v_c.

At some point after attaining velocity v_c the fabric approaches its full outward expansion and decelerates; the dust deposit, however, tends to continue travelling radially outward. If the adhesion force binding the dust to the fabric is less than the peak deceleration force caused when the fabric substrate slows as the bag reaches full expansion, the dust will separate from the fabric.

At least one other mechanism could operate to remove deposited dust during a cleaning pulse. Besides flexing the fabric, the pulse causes air to pass in the reverse direction through the fabric and dust; this reverse air flow could reentrain and remove deposited dust particles. Löffler(7) has summarized the available experimental data concerning "blowoff" of particles from fibers. The velocities needed to remove a deposited particle are always much higher than the velocity at which the particles were deposited. Smaller particles are more difficult to remove than larger particles because of their larger adhesive-to-drag force ratio. Even relatively large particles need rather high velocities to blow them off fibers. For example, Larsen(8) found that a velocity of 20 m/s was required to remove the first 16 μm diameter glass sphere from an 830 μm glass fiber.

Löffler concluded that velocities of at least 10-20 m/s are required in most cases to remove particles from fibers. The velocities attained during the reverse flow of air from a jet-pulse, however, are much lower than this. Dennis(2) estimated the average reverse-air velocity during cleaning to be approximately 150 mm/s; average velocities of 30-50 mm/s were measured in our laboratory. It thus appears that the reverse flow of air plays little part in removing dust from the fabric, and that any dust which is removed is due solely to the fabric motion.

Reverse air may help flush out particles from the fabric or dust deposit that have been separated from the fabric or deposit by another process besides "blow-off." In this case, reverse air helps make evident the effect of that other cleaning process, but must not be thought responsible itself for causing the separation.

EXPERIMENTAL PROGRAM

The experimental program described here was undertaken to measure the efficiency of dust removal from a standard needle-punched polyester felt using resuspended fly ash as the test dust. The experiments were performed on a bench-scale test apparatus that allowed cleaning efficiency and redeposition to be isolated from each other - a difficult task in pilot or full scale experiments. The test program duplicated conditions used in measuring the fractional cleaning efficiency, ε, on a pilot-scale pulse-jet fabric filter(1,3,5). Since the bench-scale tests measured the fraction of dust removed from the fabric (α), the fraction of removed dust which does not redeposit (β) could be determined by solving Equation (5-9) for β, and the relative contributions to dust retention of cleaning inefficiency and redeposition would be known.

Experimental Apparatus

The experimental apparatus consisted of two components, corresponding to the dust deposition and dust removal phases of a pulse-jet filtration cycle. The equipment used in the dust deposition phase is shown in Figure (5-1). A Wright dust feeder (10) was used to generate a fly ash aerosol with mass concentrations typical of those used in our pilot-scale tests(9). Dust-laden air was drawn by a blower through a sample of the fabric being tested; air flowrate was monitored with an orifice meter and controlled by varying the voltage to the blower motor with an autotransformer.

The dust feeder injected the test aerosol directly into a 30 cm square, 1.8 m long vertical inlet duct; the resulting downward flow eliminated size-classification by gravity settling at the low duct velocities needed in a bench-scale test. The test fabric was held in a frame and positioned directly below the inlet duct; fabric support on the clean air side was provided by wires spaced the same distance as those on the support cage of a standard pulse-jet filter. Rough estimates of the amount of dust deposited on the fabric sample at any time could be made by monitoring the dust feed rate and dust deposit pressure drop.

The apparatus for removing dust from the fabric is shown in Figure (5-2). The frame containing the dust-laden fabric was removed from the dust deposition system and placed on the end of the 1.8 m long dropping-arm. The dropping-arm was then rotated

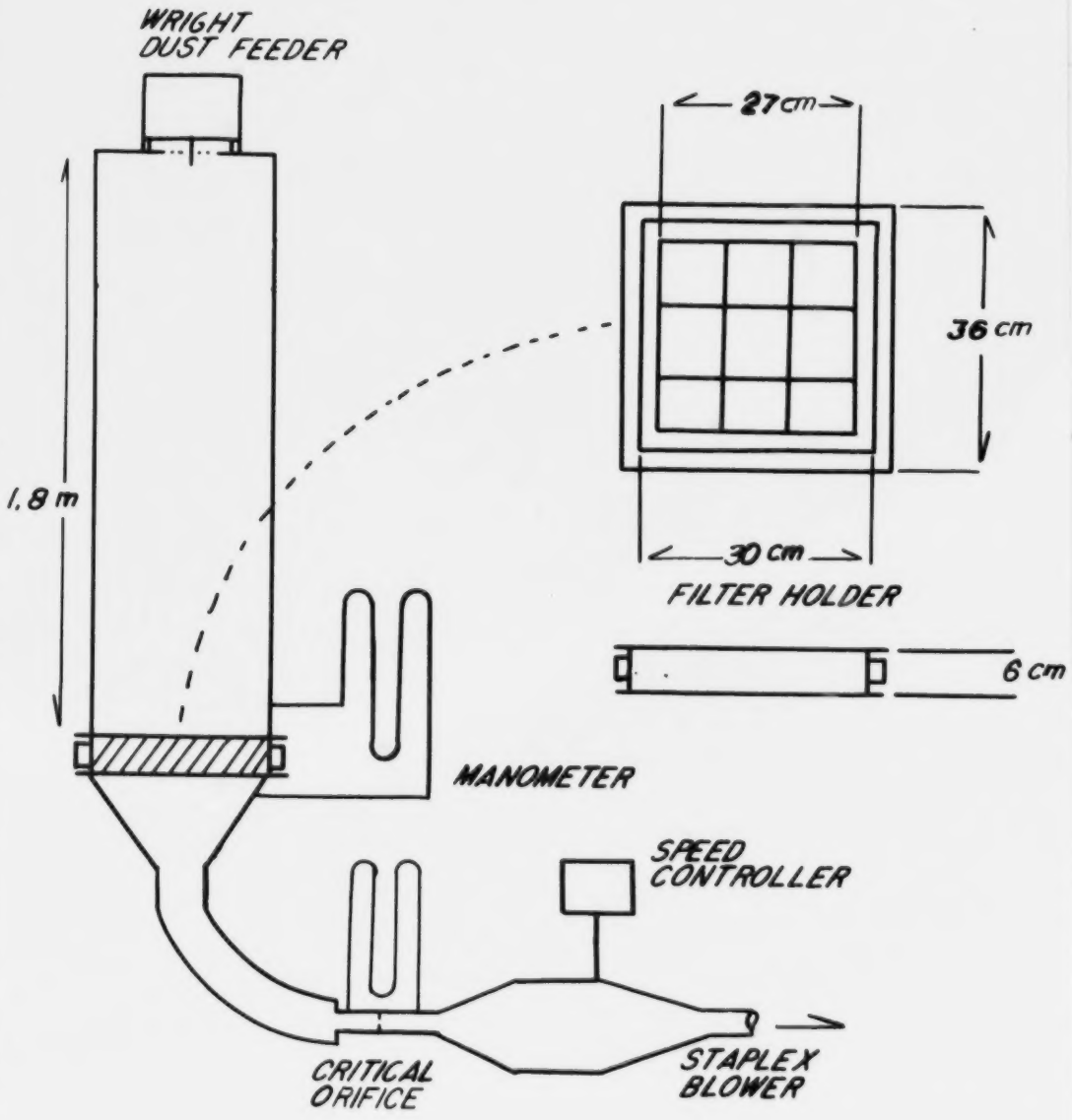

Figure 5-1. Dust collection apparatus.

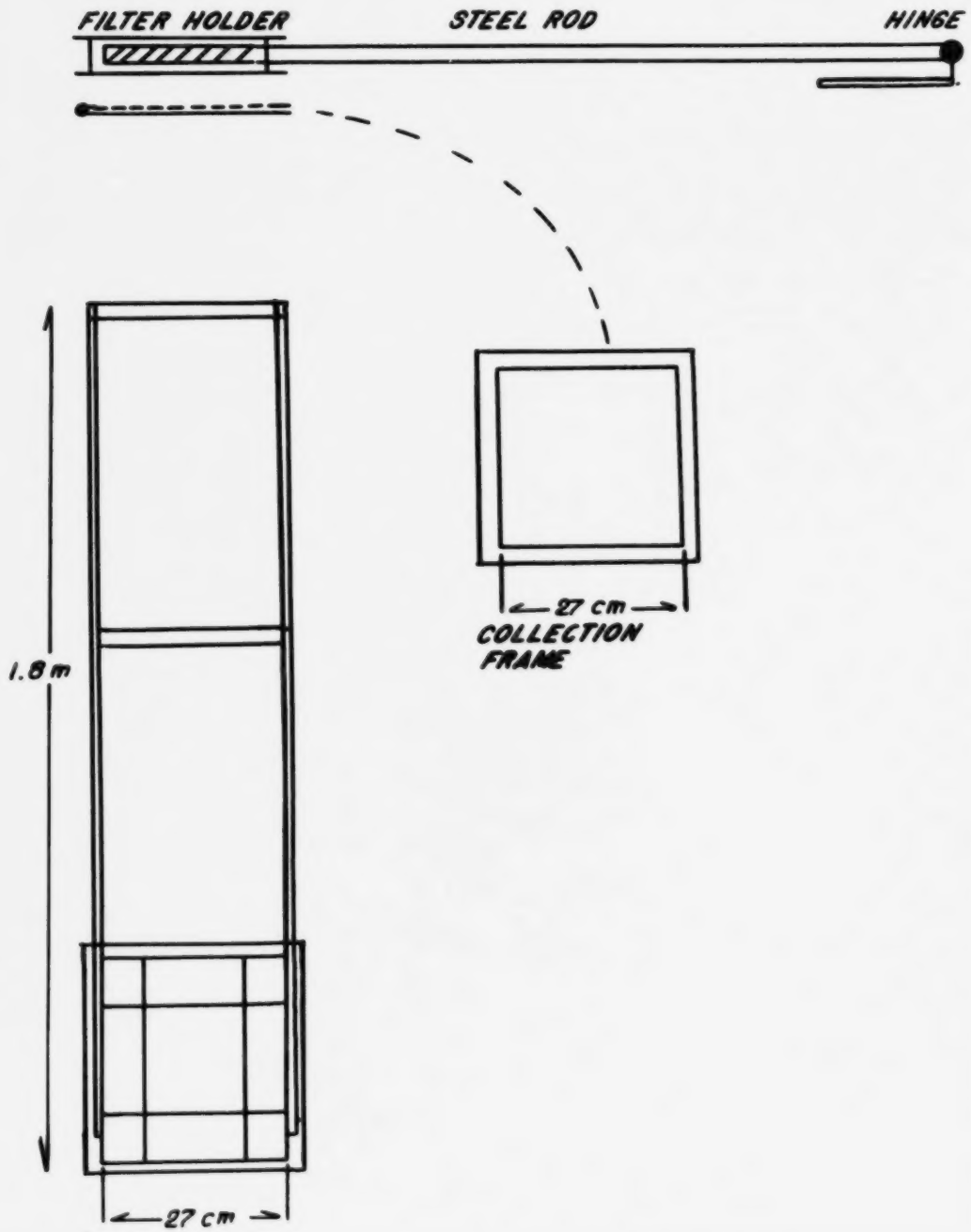

Figure 5-2. Fabric cleaning apparatus.

from the vertical position and supported at a predetermined height above the dust collection plate, dust-deposit-side down. When the support rod was removed, the frame, fabric, and dust deposit fell under gravity until the frame hit the collection plate. When the frame hits the collection plate the fabric and dust deposit have a velocity, v_c, given by:

$$v_c = (2gh)^{1/2} \qquad (5\text{-}10)$$

where g is the acceleration due to gravity and h is the height from which the frame is dropped. The drop height, h, can be selected to give, within the limits of the apparatus, any desired velocity on impact.

After impact, the fabric and dust will decelerate and come to rest; if v_c is equal to the maximum velocity attained by the fabric during a cleaning pulse in a full-scale pulse-jet filter, the deceleration should duplicate the cleaning action of an actual pulse. The removed dust was collected on a sheet of paper in the collection plate and was subsequently weighed to determine the mass of dust removed from the fabric.

The rotating dropping-arm design was selected to give the frame stability and ensure a completely flat impact with little falling friction to oppose the force of gravity. The large radius of rotation (1.8 m) was selected so that the angle subtended during the drop was very small (0.01-0.12 rad), causing the fabric to travel virtually in a linear, vertical path.

Tests Performed

The fraction of dust removed from the fabric, α, was measured as a function of three independent variables in a factorial design experiment. The independent variables tested were the superficial filtration velocity, v_f, the fabric cleaning velocity, v_c, and the dust deposit areal density, w. The last two quantities were tested because theoretical work done previously (6) suggested that α should depend strongly on cleaning velocity and dust deposit areal density. Previous work(11) has also demonstrated that the specific resistance of a dust deposit increases with increasing filtration velocity; since a dust deposit with a higher specific resistance may be more tightly bound to the fabric and be more difficult to remove, filtration velocity was included as a test variable.

The three independent variables were each tested at two levels, resulting in the measurement of fractional removal efficiencies for eight combinations of the variables. Filtration velocity was tested at 50 mm/s and 150 mm/s, which represent the extremes of velocity normally tested in the Harvard pilot-

scale pulse-jet fabric filter(1,3,9). Few data are available on the velocities attained by fabrics during cleaning; Dennis and Wilder(2) performed experiments on polyester needled-felt bags filtering fly ash and found that under typical conditions the fabric reached a maximum velocity of 1.4 m/s. In this test program, velocities of 0.7 m/s and 2.1 m/s were selected to bracket this velocity.

Dust deposit areal densities have been measured on the bags used in the HACl pulse-jet fabric filter during previous experimental programs(1,3). When filtering at velocities of 50-150 mm/s, dust deposit areal densities typically range from 400-800 g/m^2; the extremes of this range were selected for the two levels in this set of experiments.

All experiments were run using the same sample of polyester needled-felt, which was thoroughly cleaned in a high velocity airstream before each experiment. The new fabric weighed 540 g/m^2, had a permeability of 150 mm/s at 129 Pa, and had no surface treatment. A complete experiment consisted of a series of cleaning cycles during which the test fabric was repeatedly loaded with the desired amount of dust and cleaned by dropping.

Since the fraction of dust removed varied from cleaning cycle to cleaning cycle, criteria were needed to determine when to end each experiment. Preliminary tests indicated that α sometimes showed large variations on the first few cleaning cycles, but then tended toward an equilibrium value. These results led to the following arbitrary criteria for completing an experiment: 1) each experiment would contain at least ten cycles; 2) after the tenth cycle the average (α) and standard deviation (σ_a) of the previous five values of α would be calculated; and 3) if $\sigma_a < 0.25\ \bar{\alpha}$ and the last value of α was neither the largest nor the smallest measured on any cycle, the experiment was completed; if not, another cycle was run. The value of α obtained from each experiment was the average value from the last five cleaning cycles.

RESULTS

The eight experiments were performed in random order, and equilibrium values of $\bar{\alpha}$, the fractional dust removal efficiency, were attained after 10 or 11 cycles in each case. The values of $\bar{\alpha}$ calculated at the end of each experiment are shown in Table (5-1). The fraction of dust removed by a simulated cleaning pulse ranged from 0.022 (low cleaning energy, low dust areal density, high filtration velocity) to 0.359 (high cleaning energy, high dust areal density, low filtration velocity).

The data were analyzed using multiple analysis of variance (ANOVA); results are summarized in Table (5-2). The analysis

TABLE 5-1. MEASURED FRACTIONAL DUST REMOVAL EFFICIENCY, $\bar{\alpha}$

		Fabric Cleaning Velocity (m/s)			
		0.7		2.1	
		Dust Areal Density (g/m^2)		Dust Areal Density (g/m^2)	
		400	800	400	800
Filtration Velocity (mm/s)	50	0.031 (6)*	0.047 (1)	0.247 (3)	0.359 (7)
	150	0.022 (8)	0.029 (4)	0.224 (2)	0.305 (5)

*Numbers in parentheses indicate order in which tests were performed.

TABLE 5-2. ANALYSIS OF VARIANCE (ANOVA)

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Square (MS)	F Ratio	Probability (p)
Filtration Velocity(V)	1	13.78	13.78	7.29	<0.10
Cleaning Velocity(C)	1	1,257.56	1,267.56	671.85	<0.005
Dust Areal Density(W)	1	57.78	57.78	30.63	<0.01
C x W Interaction	1	36.55	36.55	19.37	<0.025
Error*	3	5.66	1.89	-	-
Totals	7	1,381,33			

*Obtained by pooling the V x C and V x W interaction SS with the residual SS.

found highly significant variations in dust removal efficiencies between cleaning velocities ($p < 0.005$) and between dust deposit areal densities ($p < 0.01$). A consistent variation between filtration velocities was also measured but was much less significant ($p < 0.10$). The interaction between cleaning velocity and dust areal density also had a significant variance ($p < 0.025$).

DISCUSSION

Effect of Cleaning Velocity

The data summarized above indicate that variations in the velocity attained by a fabric during cleaning have the greatest effect on the amount of dust removed from the fabric. This is clearly seen in Figure (5-3), where the average dust removal efficiency for the two test cleaning velocities is plotted against cleaning cycle. Also included for comparison is the result of one additional test performed at 1.4 m/s, the "typical" cleaning velocity reported by Dennis and Wilder(2).

At the higher cleaning velocities the fraction of dust removed was very high for the first few cleaning cycles, but dropped off rapidly and approached an equilibrium value after 10-20 cycles. Much of the initially deposited dust was apparently not tightly bound to the fabric and was thus easily removed. Over a few cleaning cycles the easily removed dust was replaced by dust which was more closely bound to the fabric, and α then approached its "true" value representative of a fabric in equilibrium from cleaning cycle to cycle.

Regression Analysis

Previous theoretical work has assumed that the fractional dust removal efficiency, α, is a function of the momentum of the dust deposit during cleaning, $v_c w$(6). This assumption was tested against the experimental results reported here by calculating the least squares power law regression equation relating α to v_c, w, and v_f. The resulting relationship is:

$$\alpha = 0.05\ v_c^{2.05} s^{0.49} v_f^{-0.20} \qquad (5\text{-}11)$$

where v_c and v_f are in m/s and w is in kg/m^2. The coefficient of multiple correlation was 0.998.

Equation (5-11) shows α to be a weak function of v_f, as was expected; not expected was the extremely good correlation between α, the square of the cleaning velocity, and the square root of the dust deposit areal density. The quantity $v_c^2 w^{1/2}$ has no obvious physical meaning; however, the presence of the v_c^2 term may indicate that α is a function of the kinetic energy of

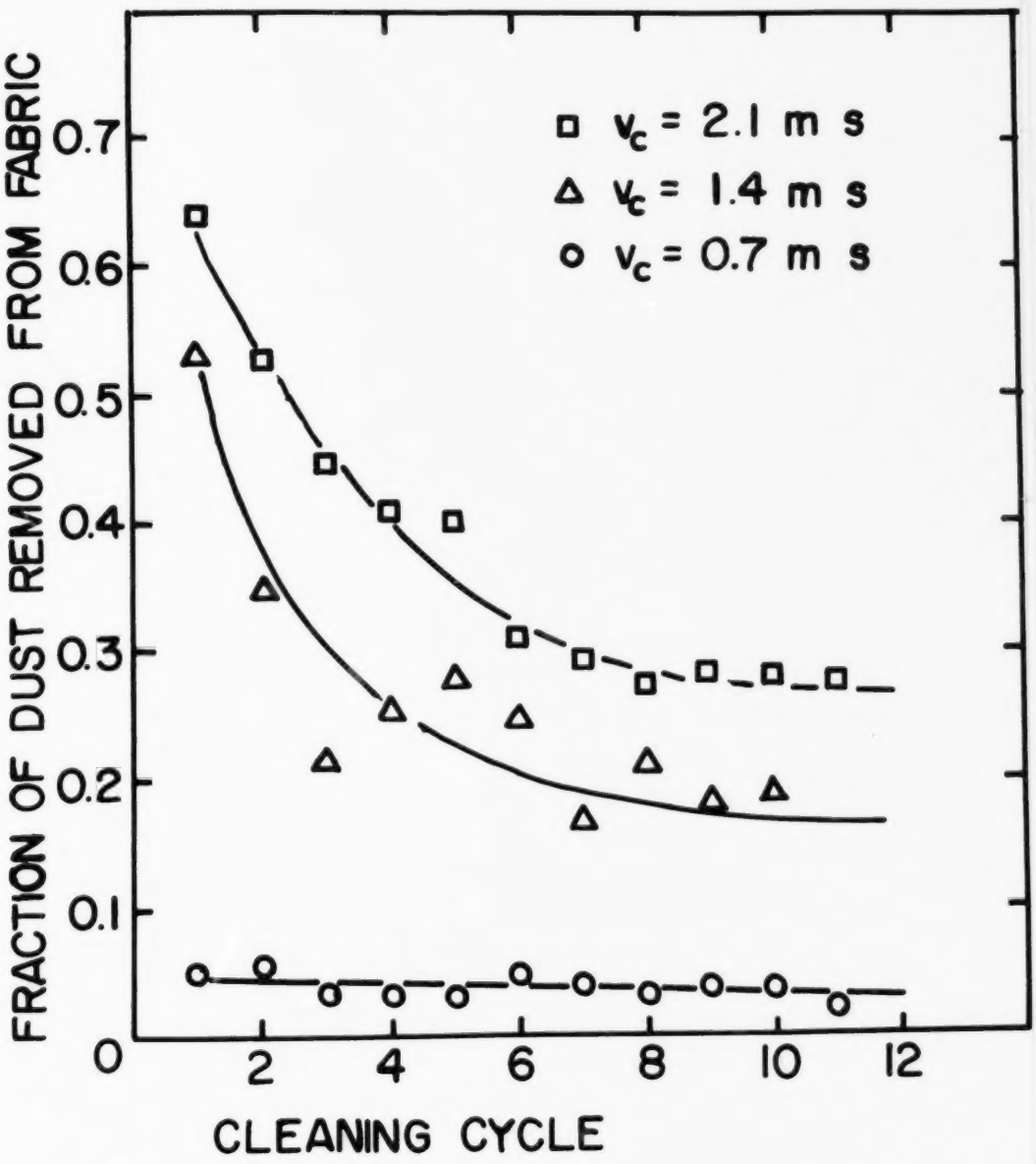

Figure 5-3. Average fraction of dust removed per cleaning cycle for each cleaning velocity.

the dust deposit rather than its momentum.

This hypothesis was tested by calculating the power law regression equation between α and E_K, the area-specific kinetic energy of the dust deposit:

$$E_K = v_c^2 w/2 \qquad (5\text{-}12)$$

The least-squares correlation equation is:

$$\alpha = 0.22\ E_K^{1.00} \qquad (5\text{-}12)$$

with a correlation coefficient of 0.98. The fraction of dust removed from the fabric is plotted as a function of E_K in Figure (5-4), along with the regression line from Equation (5-13). The excellent correlation between α and E_K indicates strongly that the amount of dust removed from a fabric is proportional to the maximum kinetic energy developed by the dust deposit as a consequence of cleaning.

The data from these experiments correlate most closely with dust deposit kinetic energy. However, the correlation with dust deposit momentum is also very good (linear least-squares correlation coefficient of 0.92) and not significantly different from that found for the correlation with dust deposit kinetic energy. This excellent correlation indicates that the pressure drop model developed previously(6), which postulates a functional relationship between ε and $v_c w$, is supported by the data presented here.

Effects of Low Cleaning Efficiency

Once equilibrium was established, a relatively small percentage of the total dust mass was removed on each cleaning cycle. This percentage (α) ranged from 2-5% for low cleaning velocities to 20-35% for high cleaning velocities, while the single test at the "normal" cleaning velocity gave a percentage removal in the 10-20% range. It is important to note that α, while showing a strong dependence on cleaning velocity, was always closer to zero than to unity, even at very high cleaning velocities. These tests indicate, therefore, that the large amount of dust measured on a pulse-jet filter at equilibrium is not primarily due to redeposition of dust removed by the cleaning pulse. A major factor affecting the amount of dust on a pulse-jet cleaned felt is evidently the failure of the cleaning pulse to remove dust from the fabric.

These concepts can be seen in data taken from the Harvard pulse-jet fabric filter(3). Results from one typical experiment

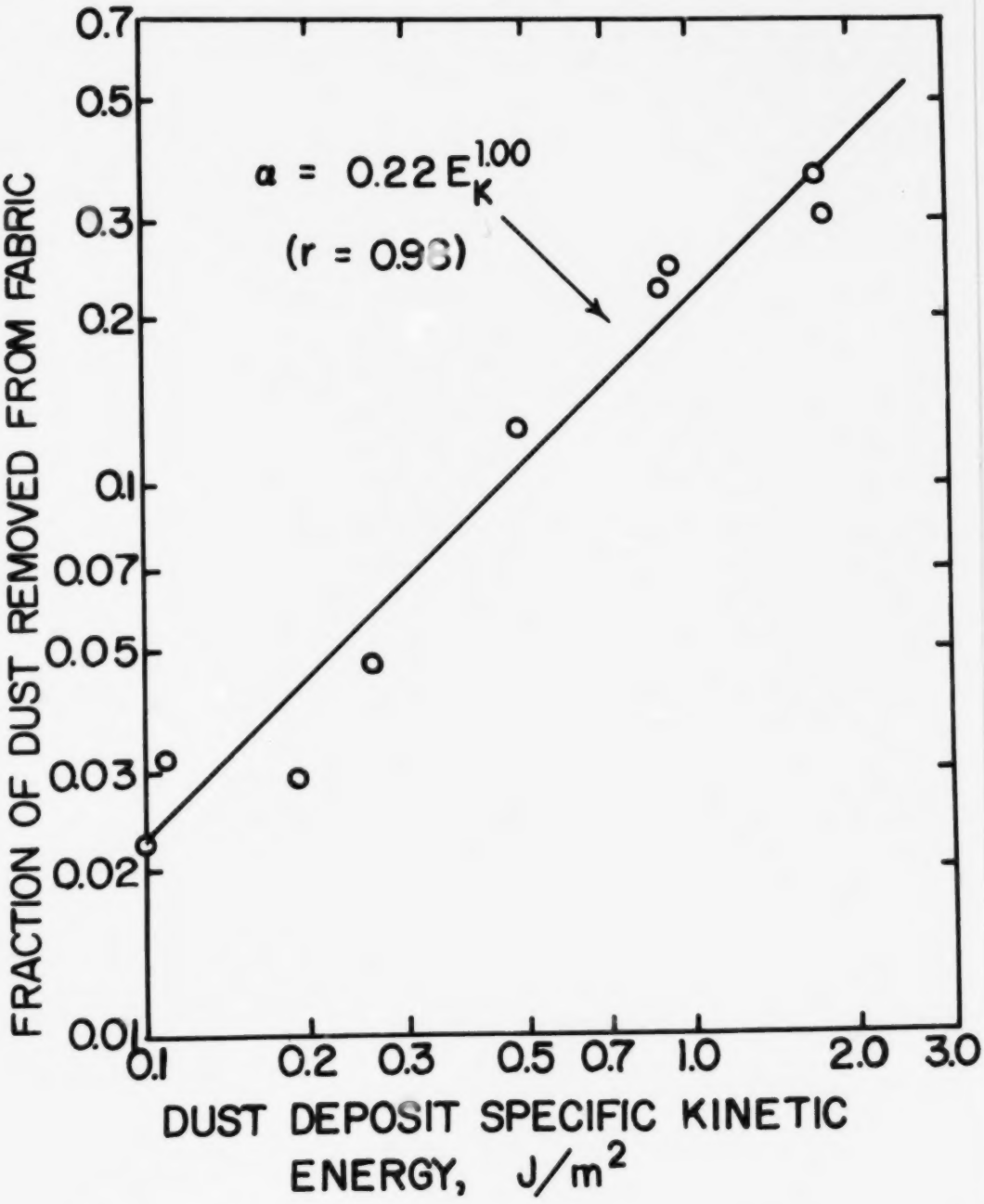

Figure 5-4. Fraction of dust removed as a function of dust deposit specific kinetic energy.

at high filtration velocity are shown in Table (5-3); also shown in the table are comparable results from the bench-scale fabric tests.

TABLE 5-3. TYPICAL RESULTS FROM PILOT-SCALE AND BENCH-SCALE TESTS

1. Pilot-Scale Test

   A. Experimental Conditions

      v_f = 100 mm/s (20 ft/min)
      w_o = 3.1 g/m^2 (6.3 x 10^{-4} lb/ft^2)
      v_c* = 1.4 m/s (280 ft/min)

   B. Results

      w = 434 g/m^2 (0.09 lb/ft^2)
      Δp = 1.13 kPa (45.6" H_2O)
      Δp_f = 85 Pa (0.3" H_2O)

II. Bench-Scale Test

   A. Experimental Conditions

      v_f = 100 mm/s (20 ft/min)
      v_c = 1.4 m/s (280 ft/min)
      w = 487 g/m^2 (0.10 lb/ft^2)

   B. Results

      α = 0.125

*not measured - taken from Dennis and Wilder(2)

When a pulse-jet filter is at equilibrium, the amount of dust falling to the hopper must equal the amount of dust added during a cleaning cycle:

$$m_h = w_o A \tag{5-14}$$

where A is the total fabric area. Since by definition $w = m_b/A$, Equation (5-3) can be written:

$$\varepsilon = \frac{w_o}{w} \tag{5-15}$$

The actual fraction of dust reaching the hopper for the experiment shown in Table (5-3) is very small:

$$\varepsilon = \frac{3.1 \text{ g/m}^2}{434 \text{ g/m}^2} = 0.007 \tag{5-16}$$

The portion of dust removed from the fabric in the bench-scale tests (α) equalled 0.125. The fraction of removed dust which did not redeposit can now be calculated:

$$\beta = \frac{\varepsilon}{\alpha} \qquad (5\text{-}9)$$

$$\beta = \frac{0.007}{0.125} = 0.06 \qquad (5\text{-}17)$$

In this example, both cleaning inefficiency (12.5% removed) and high redeposition (6% not redeposited) contribute to the low dust removal efficiency and resulting high pressure drop. When this is the case, either increasing cleaning efficiency or reducing redeposition would have a significant effect on w and Δp. For example, if α and/or β could be improved so that the cleaning efficiency (ε) was doubled (1.4% rather than 0.7%) both w and Δp would be halved(4).

SUMMARY AND CONCLUSIONS

Bench-scale tests of a non-woven polyester needled felt filtering fly ash indicate that pulse-jet cleaning may be very inefficient at removing deposited dust. Experiments performed over a wide range of fabric cleaning velocities measured dust removal efficiencies ranging from 2 to 36%. Tests at a cleaning velocity thought to be typical of velocities attained in full-scale systems resulted in a dust removal efficiency of 12.5%.

The inability of a fabric filter cleaning system to remove a large fraction of the deposited dust can have a serious adverse effect on system pressure drop. The pulse-jet cleaning system has many advantages over other fabric filter cleaning systems, but the inability of a pulse of compressed air to remove most of the dust deposited on the fabric prevents a pulse-jet system from performing even more advantageously.

The fraction of dust removed from a non-woven fabric during cleaning was found to be closely correlated with the kinetic energy attained by the dust deposit during cleaning. If kinetic energy could be more efficiently coupled to the dust deposit, either by improving pulse-jet cleaning or by applying new cleaning methods, a non-woven fabric filter might operate at much greater filtration velocities or lower pressure drops than those new used.

NOMENCLATURE

A	total fabric area (m^2)
E_K	area-specific kinetic energy of the dust deposit (J/m^2)
g	acceleration due to gravity (m/s^2)

h	frame drop height (m)
K_1	fabric resistance (Pa-m/s)
K_2	dust deposit specific resistance (s^{-1})
m_a	dust deposit mass after cleaning (kg)
m_b	dust deposit mass before cleaning (kg)
m_h	mass of dust falling to the hopper (kg)
v_c	maximum velocity during cleaning (m/s)
v_f	superficial filtration velocity (m/s)
w	dust deposit areal density (kg/m^2)
w_o	incremental dust deposit areal density (kg/m^2)
α	fabric cleaning coefficient
β	hopper fallout coefficient
γ	dust retention coefficient
Δp	equilibrium pressure drop (Pa)
Δp_d	pressure drop across the dust (Pa)
Δp_f	pressure drop across the fabric (Pa)
ε	dust removal coefficient
σ_α	standard deviation of α

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